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(54) IMPROVEMENTS IN OR RELATING TO ALUMINIUM ALLOYS

(71) We, UNITED KINGDOM ATOMIC ENERGY AUTHORITY, London, a British Authority, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to wrought aluminium alloys, and in particular to aluminium based alloys containing copper, magnesium, silicon, manganese and incidental impurities.

According to the invention aluminium based alloys contain copper 3.5—5.0 wt %, magnesium 0.2—1.0 wt %, silicon 0.5—1.0 wt %, manganese 0.3—1.5 wt %, silver 0.1—1.0 wt %, remainder aluminium with incidental impurities including iron up to 0.7 wt % maximum.

A more restricted range of alloys acccording to the invention is the range represented by the specification: copper 4.0—4.7 wt %, magnesium 0.45—0.8 wt %, silicon 0.7—0.9 wt %, manganese 0.6—0.9 wt %, silver 0.2—0.7 wt %, remainder aluminium with incidental impurities including iron up to 0.5 wt % maximum.

Alloys according to the invention when given conventional heat treatment, for example solution treated at 500°C. for 16 hours, cold water quenched followed by aging at 160°C. for 30 hours have been shown to possess high room temperature tensile properties which are improved as compared with the room temperature tensile properties of the silver free alloys when similarly heat treated.

Typically alloys in accordance with the invention but with zero silver content possess an average room temperature 0.1% proof stress averaging 27.5 tons/in^2, an average ultimate tensile stress (UTS) averaging 31.5 tons/in^2 and a percentage elongation of about 10%. By way of comparison alloys in accordance with the invention have been found to possess a room temperature 0.1% proof stress generally in the range 27.8—29 tons/in^2, a UTS in the range 31.8—32.8 tons/in^2 whilst retaining a percentage elongation at least as good as that of the silver free alloys. It has been found that in alloys in accordance with the invention such improved room temperature tensile properties are largely maintained at elevated temperatures in the range 80—120°C.

Alloys in accordance with the invention have also been found to possess an improved creep resistance at elevated temperatures as compared with the silver free alloys. Having established improved creep resistance at elevated temperatures, it is a logical expectation that improved creep resistance at room temperature will be experienced.

In the case of the silver free alloys it has been found that a long term soaking in a condition of no applied stress at a temperature in the range 70—150°C. for a period of from 100 to 1000 hours results in an improvement in the room temperature and elevated temperature tensile properties and in the room temperature creep resistance of such alloys. It has also been found that a long term soaking as aforesaid is similarly advantageous with respect to the silver containing alloys in accordance with the invention.

Examples of alloys in accordance with the invention and containing silver additions in

the range 0.1—1.0 percent are given below. Examples (b) and (g) are slightly outside the said silver range. Test results are also quoted showing the effect of such silver additions in giving an improvement in the room temperature and elevated temperature tensile properties of the alloys, in giving an improvement in the room temperature and elevated temperature creep resistance of the alloys. The later results also show the effect of a long term soaking in a condition of no applied stress in giving a firmer improvement in the room temperature tensile properties, elevated temperature tensile properties and room temperature creep resistance of the alloys.

In each case tests in respect of silver free alloys are given for comparison.

1) *The addition of silver in the range 0.1—1.0 wt % improves the room temperature tensile properties*

Wrought form of test specimens: Forged

Heat Treatment

Solution treatment by heating for 16 hours at 500°C. followed by a cold water quench and precipitation hardening by heating for 20 hours at 170°C.

	Composition						Room Temperature Tensile Tests		
	Cu	Mg	Si	Mn	Ag	Fe	0.1% PS (Tons/in²)	UTS (Tons/in²)	% EL
(a)	4.21	0.71	0.76	0.77	—	0.13	27.8	32.0	11
(b)	4.14	0.69	0.79	0.80	0.09	0.15	27.9	31.8	12
(c)	4.17	0.70	0.81	0.82	0.19	0.15	27.9	32.1	12
(d)	4.11	0.71	0.82	0.81	0.28	0.16	27.9	32.1	11
(e)	4.10	0.71	0.82	0.81	0.38	0.16	27.8	32.0	10
(f)	4.19	0.71	0.83	0.81	0.48	0.15	28.8	32.8	11
(g)	4.27	0.71	0.81	0.75	1.02	0.15	29.0	33.4	9
(h)	4.31	0.47	0.79	0.77	—	0.12	27.4	31.3	11
(i)	4.16	0.46	0.78	0.80	0.40	0.12	28.0	32.1	11

In the above table example (a) is given for comparison and relates to a silver free alloy. Examples (c) to (f) demonstrate the effect of the addition of increasing silver content in the range 0.1—1.0 wt %, Examples (b) and (g) having silver just outside this range.

Example (h) is also given for comparison and relates to a silver free alloy having a different base composition to that of example (a). Example (i) demonstrates the effect of an 0.4 wt % silver addition to the silver free alloy of example (h).

2) *The addition of silver improves the room temperature tensile properties of alloys having a range of compositions*

Wrought form of test specimens:

Examples (a)—(j) Forged

Examples (k)—(n) Extruded

Heat Treatment: Solution treatment by heating for 16 hours at 500°C. followed by a cold water quench and precipitation hardening by heating for 20 hours at 170°C.

	Composition						Room Temperature Tensile Tests		
	Cu	Mg	Si	Mn	Ag	Fe	0.1% PS (Tons/in^2)	UTS (Tons/in^2)	% EL
(a)	4.31	0.47	0.79	0.77	—	0.12	27.4	31.3	11
(b)	4.21	0.71	0.76	0.77	—	0.13	27.8	32.0	10
(c)	3.90	0.70	0.83	0.80	0.38	0.13	27.8	32.0	10
(d)	4.56	0.70	0.80	0.80	0.38	0.12	28.3	32.6	11
(e)	4.16	0.46	0.78	0.80	0.40	0.12	27.6	31.8	11
(f)	4.20	0.79	0.79	0.73	0.39	0.14	28.6	32.8	10
(g)	4.24	0.71	0.59	0.79	0.40	0.12	27.9	32.1	11
(h)	4.31	0.71	0.92	0.78	0.39	0.13	28.2	32.4	10
(i)	4.18	0.71	0.79	0.60	0.39	0.13	28.4	32.6	11
(j)	4.22	0.71	0.80	0.91	0.39	0.14	28.6	32.8	10
Extruded									
(k)	4.02	0.47	0.72	0.64	—	0.11	26.3	30.7	7
(l)	3.86	0.45	0.72	0.64	0.21	0.11	27.5	32.4	10
(m)	4.67	0.81	0.93	0.95	—	0.12	26.5	31.5	9
(n)	4.33	0.66	0.92	0.86	0.69	0.14	31.3	35	11

In table (2) above examples (a) and (b) are given for comparison and relate to silver free alloys. Examples (c) to (j) demonstrate the improving effect of approximately 0.4 wt % silver with variation of amounts of all the major elements. In table (2) examples (k) and (m) are also given for comparison and relate to silver free alloys whereas examples (l) and (n) respectively contain 0.21 and 0.69 wt % silver. Examples (k) to (n) show the effect of variation of all the major elements including silver between the minima and maxima.

3) *The addition of silver improves the room temperature tensile properties of alloys having a wide range of compositions*

Wrought form of test specimens: Forged

Heat Treatment

Solution treatment by heating for 16 hours at 500°C. followed by a cold water quench and precipitation hardening by heating for 20 hours at 170°C.

	Composition						Room Temperature Tensile Tests		
	Cu	Mg	Si	Mn	Ag	Fe	0.1% PS (Tons/in^2)	UTS (Tons/in^2)	% EL
(a)	4.31	0.47	0.79	0.77	—	0.12	27.4	31.3	11
(b)	4.21	0.71	0.76	0.77	—	0.13	27.8	32.3	10
(c)	3.4	0.71	0.80	0.76	0.42	0.16	27.1	31.6	12
(d)	4.98	0.71	0.82	0.77	0.42	0.15	28.7	32.3	8
(e)	4.22	0.20	0.80	0.77	0.42	0.15	25.0	29.9	12
(f)	4.33	1.03	0.81	0.76	0.42	0.10	28.1	32.2	11
(g)	4.16	0.42	0.80	0.79	0.49	0.14	29.0	32.4	10.5

In table (3) above examples (a) and (b) are given for comparison and relate to silver free alloys. Examples (c) to (g) demonstrate that the improvement in room temperature tensile properties caused by silver additions of about 0.4 wt % is effective over a wide range of base composition. Example (c)—low copper, and example (f)—high magnesium, are slightly outside the ambit of the invention. The results are mainly for wide variations in copper and magnesium which are the two elements most likely to have a significant effect on the mechanical properties.

4) *The addition of silver is effective in different wrought forms*
Heat Treatment
Solution treatment by heating for 16 hours at 500°C. followed by a cold water quench and precipitation hardening by heating for 20 hours at 170°C.

Wrought form of test specimens: Forged

	Composition						Room Temperature Tensile Tests		
	Cu	Mg	Si	Mn	Ag	Fe	0.1% PS (Tons/in²)	UTS (Tons/in²)	% EL
(a)	4.21	0.71	0.76	0.77	—	0.13	27.9	31.4	7
(b)	4.10	0.71	0.82	0.81	0.38	0.16	28.5	32.5	8

Wrought form of test specimens: Extruded Bar

	Composition						Room Temperature Tensile Tests		
	Cu	Mg	Si	Mn	Ag	Fe	0.1% PS (Tons/in²)	UTS (Tons/in²)	% EL
(c)	4.21	0.71	0.76	0.77	—	0.13	31.2	34.2	10
(d)	4.23	0.72	0.79	0.75	0.39	0.13	32.4	35.2	10

In table (4) above examples (a) and (c) are given for comparison and relate to silver free alloys. The examples (b) and (d) show that the improving effect of silver additions on the mechanical properties of alloys is not dependent on the wrought form of the alloy.

5) *The addition of silver in the range 0.1—1.0 wt % improves the elevated temperature tensile properties*
Heat Treatment:
Solution treatment by heating for 16 hours at 500°C. followed by a cold water quench and precipitation hardening by heating for 20 hours at 170°C.

Wrought form of test specimens: Forged

							Elevated Temperature Tensile Tests at:—								
							80°C			100°C			120°C		
	Cu	Mg	Si	Mn	Ag	Fe	0.1% P.S. (tons/in^2)	U.T.S. (tons/in^2)	% El	0.1% P.S. (tons/in^2)	U.T.S. (tons/in^2)	% El	0.1% P.S. (tons/in^2)	U.T.S. (tons/in^2)	% El
(a)	4.21	0.71	0.76	0.77	—	0.13	26.8	29.6	12	27.1	29.6	10	26.4	28.2	13
(b)	4.14	0.69	0.79	0.80	0.09	0.15							26.0	28.0	13
(c)	4.17	0.70	0.81	0.81	0.19	0.15							25.7	27.9	12
(d)	4.11	0.71	0.82	0.81	0.28	0.16	28.0	30.8	11	27.5	30.2	11	27.2	29.2	10
(e)	4.10	0.71	0.82	0.81	0.38	0.16	28.3	30.6	11	27.4	29.8	10	27.4	29.3	13
(f)	4.19	0.71	0.83	0.81	0.48	0.15							27.6	29.4	14
(g)	4.27	0.71	0.81	0.75	1.02	0.15							28.2	30.8	12
Wrought form of test specimens: Extruded bar															
(h)	4.21	0.71	0.76	0.77	—	0.13	29.6	32.1	17				27.8	30.1	19
(i)	4.23	0.72	0.79	0.75	0.39	0.13	30.8	33.2	18				28.8	30.8	20

In table (5) above examples (a) and (h) are given for comparison and relate to silver free alloys. The remaining examples (examples (b) and (g) are not strictly according to the invention on silver content) show the improving effect of silver additions on the mechanical properties at elevated temperatures and that the improvement is not critically dependent on the wrought form of the alloy.

6) *The addition of silver improves creep resistance*

Heat Treatment:

Solution treatment by heating for 16 hours at 500°C. followed by a cold water quench and precipitation hardening by heating for 20 hours at 170°C.

Wrought form of test specimens : Forged

	Composition						Total Plastic Strain (%) at			
							70°C/26 tonf/in²		100°C/20 tonf/in²	
	Cu	Mg	Si	Mn	Ag	Fe	500 hours	1000 hours	500 hours	1000 hours
(a)	4.21	0.71	0.76	0.77	—	0.13	.380	.400	.028	.032
(b)	4.11	0.71	0.82	0.81	0.28	0.16	.124	.130	—	—
(c)	4.10	0.71	0.82	0.81	0.38	0.16	.101	.105	.017	.018
(d)	4.27	0.71	0.81	0.75	1.02	0.15				
Wrought form of test specimens: Extruded bar										
(e)	4.21	0.71	0.76	0.77	—	0.13	.275	.32	—	—
(f)	4.23	0.72	0.79	0.75	0.39	0.13	.095	.10	—	—

In table (6) above examples (a) and (e) are given for comparison and relate to silver free alloys. The remaining examples (example (d) is not strictly according to the invention on silver content) show the improving effect of silver additions on the creep resistance. The results also show that the effect is not dependent on the wrought form of the alloy.

7) *Long term soaking in a condition of no applied stress over a range of temperatures improves the Room Temperature Tensile Properties of both silver free and silver containing alloys*

Wrought form of test specimens: Forged

Primary Heat Treatment

Solution treatment by heating for 16 hours at 500°C. followed by a cold water quench and precipitation hardening by heating for 20 hours at 170°C.

	Composition						Soaking Temp. °C	Time Hours	Room Temperature Tensile Tests		
	Cu	Mg	Si	Mn	Ag	Fe			0.1% P.S. (Tons/in²)	U.T.S. (Tons/in²)	%El
(a)	4.2	0.42	0.84	0.76	0.31	0.13	—	—	29.0	32.7	11
(b)	4.2	0.42	0.84	0.76	0.31	0.13	100	500	29.4	33.2	11
(c)	4.2	0.42	0.84	0.76	0.31	0.13	100	750	29.6	33.4	12
(d)	4.2	0.42	0.84	0.76	0.31	0.13	100	1000	29.8	33.2	10
(e)	4.2	0.42	0.84	0.76	0.31	0.13	120	250	29.8	33.4	10
(f)	4.2	0.42	0.84	0.76	0.31	0.13	120	500	28.8	33.4	13
(g)	4.2	0.42	0.84	0.76	0.31	0.13	120	750	29.6	33.9	11
(h)	4.2	0.42	0.84	0.76	0.31	0.13	120	1000	29.6	33.0	11
(i)	4.2	0.42	0.84	0.76	0.31	0.13	135	100	29.6	33.3	11
(j)	4.2	0.42	0.84	0.76	0.31	0.13	135	250	29.6	33.4	10
(k)	4.2	0.42	0.84	0.76	0.31	0.13	135	500	29.4	32.9	11
(l)	4.2	0.42	0.84	0.76	0.31	0.13	135	750	29.3	33.0	10
(m)	4.2	0.42	0.84	0.76	0.31	0.13	135	1000	28.7	33.4	13
							Second Ageing Treatment				
(n)	4.21	0.71	0.76	0.77	—	0.13	—		27.8	32.0	11
(o)	4.21	0.71	0.76	0.77	—	0.13	1000h/70°C		27.7	31.8	9
(p)	4.21	0.71	0.76	0.77	—	0.13	1000h/100°C		28.1	32.0	9
(q)	4.21	0.71	0.76	0.77	—	0.13	1000h/150°C		26.5	30.4	8
(r)	4.10	0.71	0.82	0.81	0.38	0.16	—		27.8	32.0	10
(s)	4.10	0.71	0.82	0.81	0.38	0.16	1000h/70°C		28.6	32.8	10
(t)	4.10	0.71	0.82	0.81	0.38	0.16	1000h/100°C		28.7	32.7	9
(u)	4.10	0.71	0.82	0.81	0.38	0.16	1000h/150°C		27.5	31.5	9
(v)	4.11	0.71	0.82	0.81	0.28	0.16	—		27.9	32.1	11
(w)	4.11	0.71	0.82	0.81	0.28	0.16	1000h/100°C		29.2	33.2	10
(x)	4.31	0.47	0.79	0.77	—	0.12	—		27.4	31.3	11
(y)	4.31	0.47	0.79	0.77	—	0.12	1000h/100°C		28.2	32.2	11
(z)	4.21	0.71	0.76	0.77	—	0.13	—		27.8	32.0	11
(z¹)	4.21	0.71	0.76	0.77	—	0.13	1000h/100°C		28.1	32.0	9

In table (7) above examples (b) to (m) demonstrate the effect of an additional prolonged soaking in a condition of no applied stress at elevated temperature in improving the room temperature tensile properties of alloys containing 0.31 wt % silver. Example (a) relates for comparison to an alloy which has not been given an additional soaking treatment.

Examples (b) to (m) show that the effect depends both on the duration and temperature of the soaking. Within certain limits the lower the temperature of the soaking the longer is the time required for maximum enhancement of the mechanical properties. Conversely the higher the temperature of the soaking the shorter is the time required for maximum enhancement of the mechanical properties. Also maximum enhancement of mechanical properties is generally achieved by soaking at the lower temperatures for the longer times.

Examples (o), (p) and (q) show the variation of the effect with temperature in soaking silver free alloys for 1000 hour periods. Example (n) relates for comparison to a silver free alloy of similar base composition to the alloys of examples (o) (p) and (q) but which has not been given an additional soaking treatment.

Examples (s) (t) and (u) show the variation of the effect with temperature in soaking alloys containing 0.38 wt % silver for 1000 hour periods. Example (r) relates for comparison to an alloy of similar composition to the alloys of examples (s) (t) and (u) (i.e. also containing 0.38 wt % silver but which has not been given an additional soaking treatment).

Example (w) shows the effect of soaking an alloy containing 0.28 wt % silver for 1000 hours at 100°C. as compared with a similar alloy (example v) which has not been given an additional soaking treatment. Comparison of example (v) with example (s) (t) and (u) demonstrates that the effect applies to alloys of different silver content.

Examples (x) (y) (z) and (z[1]) demonstrate that the effect applies to silver free alloys of different base compositions (i.e. containing 0.47 wt % magnesium in examples (x) and (y) and containing 0.71 wt % magnesium in examples (z) and (z[1]).

8) *Long term soaking in a condition of no applied stress at an elevated temperature (e.g. for 1000 hours at 100°C.) improves the Elevated Temperature Tensile Properties of both silver free alloys and alloys containing silver.*

Wrought Form of Test Specimens: Forged
Primarly Heat Treatment

Solution treatment by heating for 16 hours at 500°C. followed by a cold water quench and precipitation hardening by heating for 20 hours at 170°C.

	Composition						Second Ageing Treatment	80°C			Elevated Temperature 100°C			Tensile Tests at 120°C		
	Cu	Mg	Si	Mn	Ag	Fe		0.1% P.S. ($Tons/in^2$)	U.T.S. ($Tons/in^2$)	% El	0.1% P.S. ($Tons/in^2$)	U.T.S. ($Tons/in^2$)	% El	0.1% P.S. ($Tons/in^2$)	U.T.S. ($Tons/in^2$)	% El
(a)	4.21	0.71	0.76	0.77	—	0.13	—	26.8	29.6	12	27.1	29.6	10	26.4	28.2	13
(b)	4.21	0.71	0.76	0.77	—	0.13	1000h/100°C	27.8	30.2	9	27.2	29.5	13	27.4	29.2	12
(c)	4.11	0.71	0.82	0.81	0.28	0.16	—	28.0	30.8	11	—	—	—	—	—	—
(d)	4.11	0.71	0.82	0.81	0.28	0.16	1000h/100°C	28.4	31.4	8	—	—	—	—	—	—
(e)	4.10	0.71	0.82	0.81	0.38	0.16	—	28.3	3.06	11	27.4	29.8	10	27.4	29.3	14
(f)	4.10	0.71	0.82	0.81	0.38	0.16	1000h/100°C	28.8	31.8	8	28.6	31.1	7	27.8	29.8	7

In table (8) above examples (a) (c) and (e) relate to alloys of similar base composition and containing respectively no silver, 0.28 wt % silver, and 0.38 wt % silver, the alloys (a) (c) and (e) not having been given any additional soaking treatment. Alloys (b) (d) and (f) correspond to and are of similar composition to alloys (a) (c) and (e) but have been soaked in a condition of no applied stress for 1000 hours at 100°C. and demonstrate the improvement in elevated temperature mechanical properties obtained by such a further soaking treatment.

9) *Long term soaking in a condition of no applied stress at an elevated temperature (e.g. for 1000 hours at 100°C.) improves the creep resistance of both silver free alloys and alloys containing silver.*

Wrought form of test specimens: Forged

Heat Treatment

Solution treatment by heating for 16 hours at 500°C. followed by a cold water quench and precipitation hardening by heating for 20 hours at 170°C.

Cu	Mg	Si	Mn	Ag	Fe	Second Ageing Treatment	Total Plastic Strain % at 70°C/26 tonf/in² 500 hours	1000 hours
	Composition							
4.21	0.71	0.76	0.77	—	0.13	—	.380	.400
4.21	0.71	0.76	0.77	—	0.13	1000h/100°C	.140	.160
4.10	0.71	0.82	0.81	0.38	0.16	—	.101	.105
4.10	0.71	0.82	0.81	0.38	0.16	1000h/100°C	.040	.045

Alloys according to the invention may also include minor improving elements such as one or more of titanium, lithium, beryllium, zirconium, vanadium, boron, cadmium and germanium. These may be present each up to 0.5 wt % maximum and in total not more than 1.0 wt %.

WHAT WE CLAIM IS:—

1. Aluminium based alloys containing 3.5—5.0 weight percent copper, 0.2—1.0 weight percent magnesium, 0.5—1.0 weight percent silicon, 0.3—1.5 weight percent manganese, 0.1—1.0 weight percent silver, remainder aluminium with incidental impurities including iron up to 0.7 weight percent maximum.

2. Aluminium based alloys containing 4.0—4.7 weight percent copper, 0.45—0.8 weight percent magnesium, 0.7—0.9 weight percent silicon, 0.6—0.9 weight percent manganese, 0.2—0.7 weight percent silver, remainder aluminium with incidental impurities including iron up to 0.5 weight percent maximum.

3. Aluminium alloys as claimed in claim 1 and substantially as hereinbefore described with reference to the examples given in the accompanying specification.

D. S. BOSSHARDT,
Chartered Patent Agent,
Agent for the Applicants.

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